Soil Hydraulic Property Estimation in Six Shawnee Hills Catenas

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USDA NRCS United States Department of Agriculture Natural Resources Conservation Service

USGS science for a changing world

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United States Department of Agriculture
Natural Resources Conservation Service

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Introduction

- Modeling soil-water availability depends on reliable estimation of hydrologic soil properties.
  - Climate Change
  - Land-use Change
  - Obtaining soil hydrologic properties can be costly and time consuming
- The lower Midwest region (MLRA 120) maximum annual temperature is projected to increase by approximately 2° C by 2050
  - 8.5 (~1370 ppm CO_2 by 2100) Representative Concentration Pathway (RCP)
- Precipitation is projected to remain relatively unchanged
  - Temperature increases amount of water to sustain agricultural production
- It has been shown that soil carbon (SOC) content has been linked to available water-holding capacity and saturated hydraulic conductivity (K_{sat})
  - Hydrologic soil properties are also dependent on other soil factors (PSA, Bulk Density)

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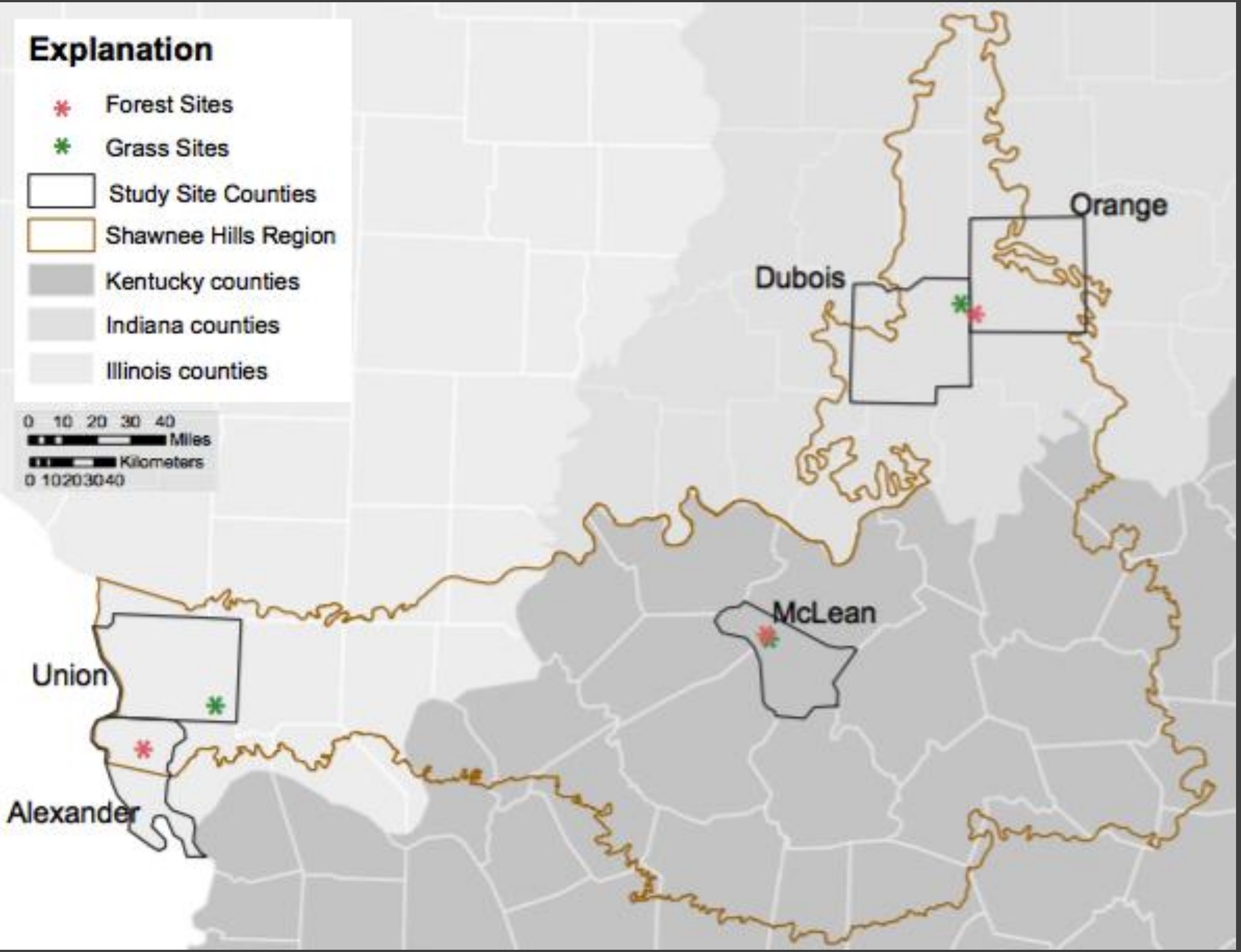
Study Overview

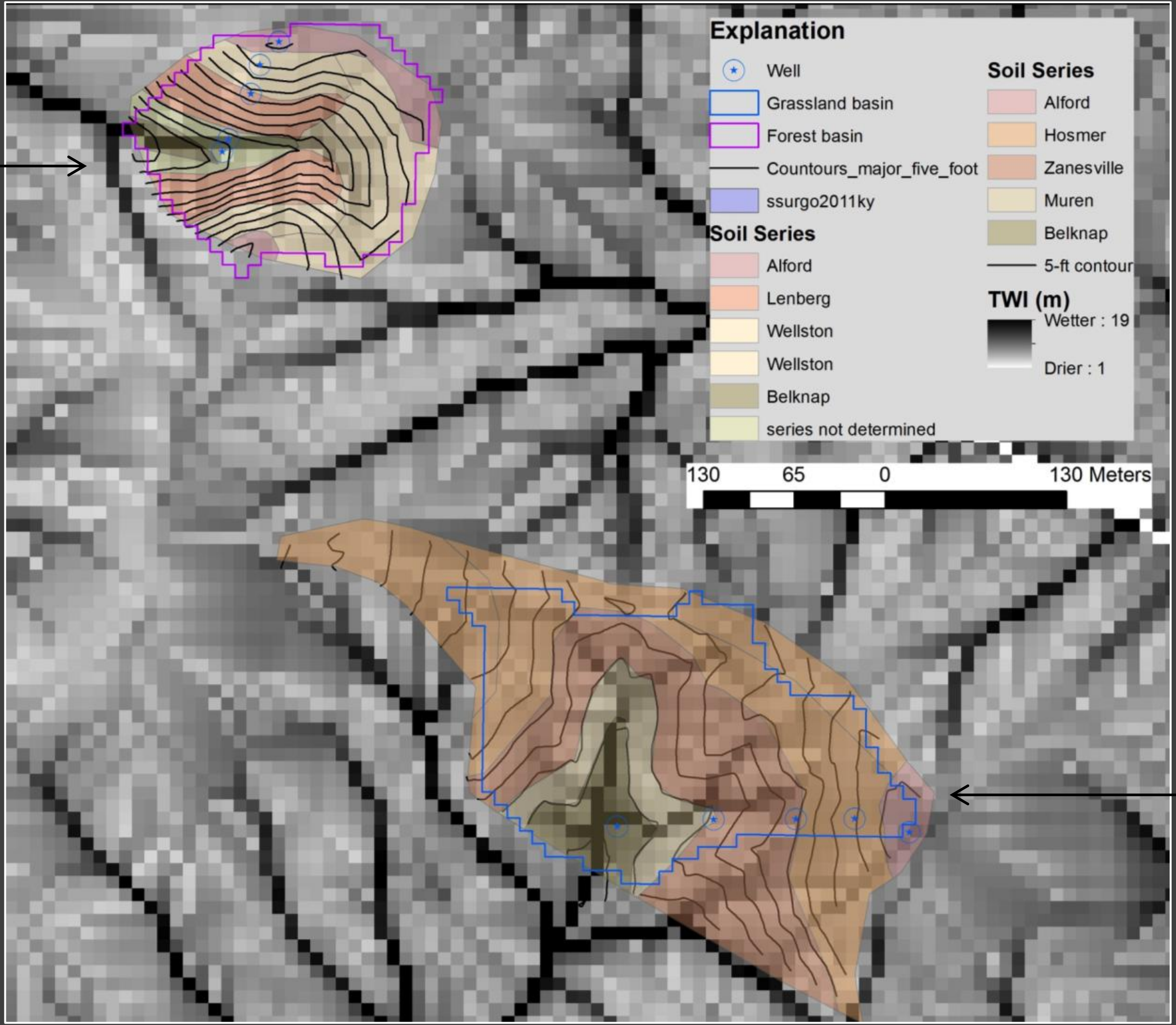


- Regional approach to estimate soil hydraulic properties
- 6 Catenas
  - 3 Forest and 3 Grassland
    - Illinois
      - Alexander County
      - Union County
    - Indiana
      - Dubois County
      - Orange County
    - Kentucky
      - McLean County

3 Paired Watersheds

Example: (McLean County, Kentucky)

Forested Site



Grassland Site

Image: TWI Kentucky Paired Catenas

- Majority of upland soils
  - Forested
  - Grassland
- Similar soils
- Similar sized watersheds
- Pedons characterized
  - Each landscape position

Field Methods

Catena Analysis

- Each catena 5 landscape positions were chosen
  - (e.g. Summit, Shoulder, Backslope, Footslope, and Toeslope)
    - Illinois Forest only 4 landscape positions
  - Pedon characterization according to standard NRCS methods
    - Schoeneberger et al. (2002)
    - from 0 - 200cm+ or limiting layer
  - K_{sat}
    - Compact Constant Head Permeameter (Amoozemeter)
    - Rates calculated using the Glover solution
      - (Amoozegar, 1992)

Image: Kentucky Forest

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Field Methods

K_{sat}

- Measurements taken at landscape each position (n= 29)
  - Within 4 m of described pit
  - 3-4 depths throughout
  - Average 5 + measurements
    - Surface horizons are depth weighted
- Total of 100 *in-situ* K_{sat} measurements

Lab Methods

Catena Analysis

- Particle Size Analysis (PSA)
  - Air dried and sieved <2 mm
    - Sand
      - Wet Sieving
    - Clay
      - Pipette Method
    - Silt
      - Difference
- Soil Organic Carbon (SOC)
  - Combustion

- Clod Method (Triplicate)
  - Bulk Density (BD)
  - Porosity
    - Using particle density of 2.65 g cm^{-3}
  - Plant Available Water
    - Field Capacity (33 kPa)
    - Permanent Wilting Point (1500 kPa)

Each described horizon processed according to Burt (2004)

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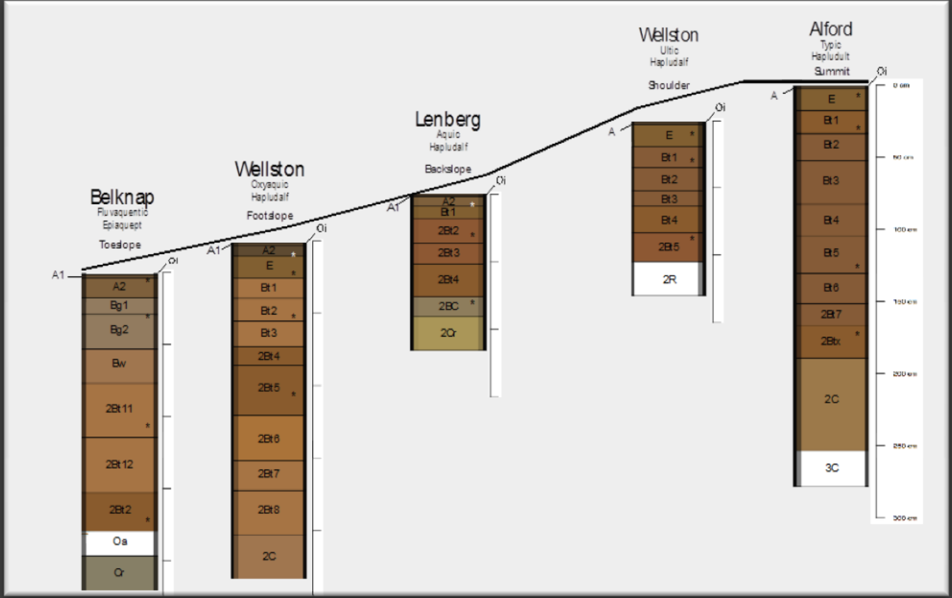
Parent Material

Loess Thickness/Stratigraphy (Summit)	State	County	Landuse
2.0 m+ loess over sandstone/shale residuum	IL	Union	Grass (CRP)
2.0 m+ loess over sandstone/shale residuum	IL	Alexander	Forested
1.0 m loess over sandstone/shale residuum	IN	Dubois	Grass (Pasture)
1.0 m loess over sandstone/shale residuum	IN	Orange	Forested
1.5 m loess over sandstone/shale residuum	KY	McLean	Grass (Hayfield)
1.5 m loess over sandstone/shale residuum	KY	McLean	Forested

- Loess Veneer
  - Peoria unit (25,000 to 12,000 yr BP)
  - Overlaying Roxana Unit (55,000 to 28,000 yr BP)
- Thickness primarily due to proximity from source



Parent Material…..continued

- Loess heavily eroded
  - Past land-use (agriculture, logging)
  - Relief (40 m ridgetop to floodplain)
- Soils originally formed in deciduous forest
  - Oak (*Quercus*)-hickory (*Carya*)
- Underlet by interbedded sandstone and shale
  - Pennsylvanian
  - Mississippian era

Objective

- The objective of this study is to test three methods for estimating soil hydraulic properties against *in-situ* measurements from six Shawnee Hills catenas.

- Total of 29 landscape positions
    - 100 Horizons

Pedotransfer Function (PTFs)

- Soil hydraulic properties at a field scale can be impractical
  - Time
  - Cost
- Need an easier way to obtain these value
- Attempts to circumvent field measurements have been in interest since 1912 (Briggs and Shantz, 1912)
- PTFs and are an attempt to obtain hard to measure soil hydraulic properties
  - Using obtainable soil properties (PSA, BD, SOC)
- Many PTFs available

Image: Kentucky Forest Toeslope

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Many Pedotransfer Functions (PTFs)

PTF	Input Parameters
Boelter, 1969 (peat soils)	BD
Campbell and Shiozawa, 1994	Sand, clay
Chapuis, 2004 (sand & gravel soils)	Effective diameter, void ratio
Dane and Puckett, 1994	clay
Jabro, 1992	Sand, silt, BD
Nemes et al., 2005	Sand, clay, BD, OM
Puckett et al., 1985	clay
Rawls and Brakensiek, 1985	Sand, clay, porosity
Rawls et al., 2006 *	**Sand, Clay, OM***
Saxton et al., 1986	Sand, clay, saturated water content
Schaap, 1999 (Rosetta)	Sand, silt, clay, BD
Schaap, 1999 (Rosetta)	Sand, silt, clay, BD, 1/3 bar water, 15 bar water
Vereecken et al., 1990	Sand, clay, BD, OM
Wösten et al., 1999	Clay, Silt, topsoil (1,0), BD, OM,
Wösten et al., 2001 (sandy soils)	Silt, BD, OM
Wösten et al., 2001 (loam & clay soils)	Clay, BD, OM

- Issues
  - Inputs not easily obtained
    - (e.g. pore radius, 33 kPa)
  - Correlated in specific soils
    - (e.g. sandy, peat, ultisols)
  - Nationwide database correlation
    - (e.g. United States, Belgium)
    - Downscaling
      - Large dataset to single points

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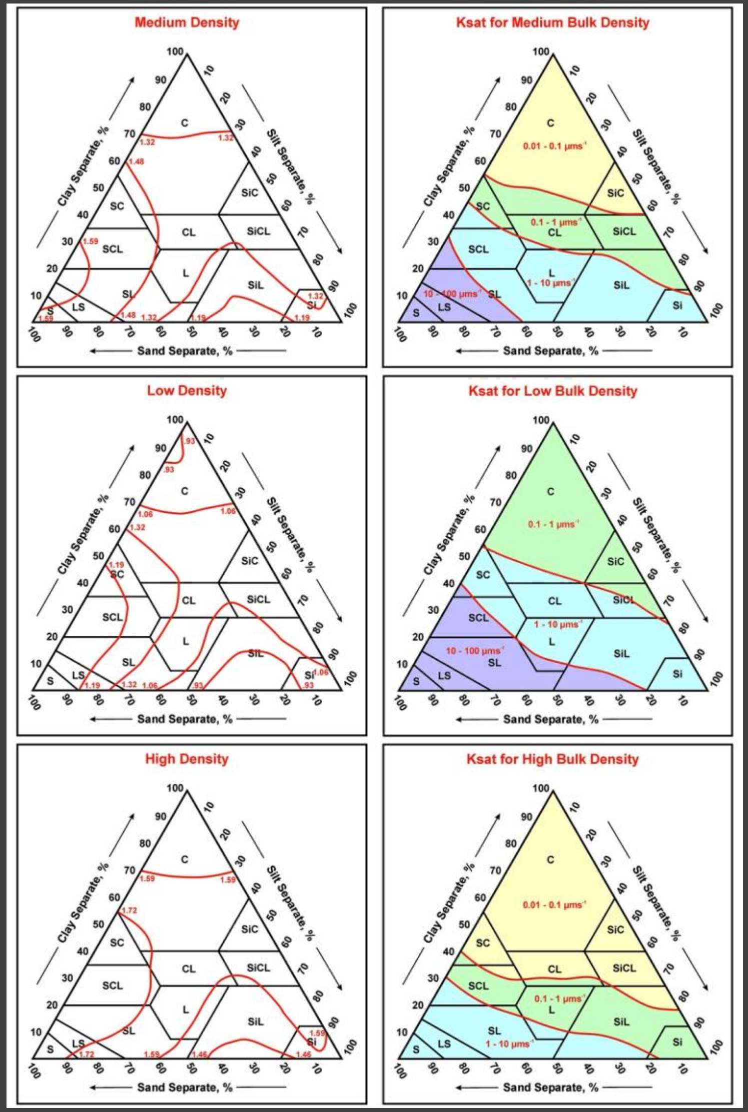
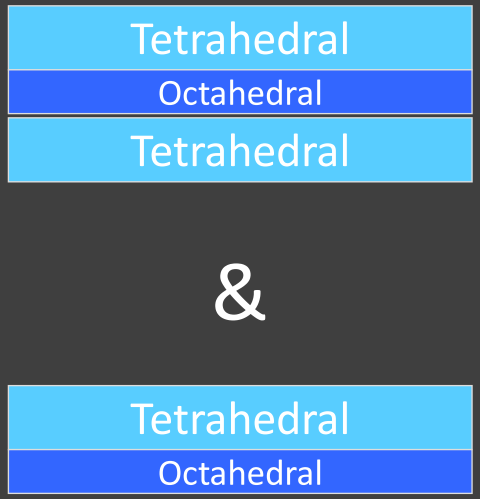
T_{PSA} K_{sat} Estimation Method

- Separates the bulk density into classes
  - (low, medium, high)
- Using the textural triangle to select the range of K_{sat}
  - PSA driven
- Converted into an R script
  - Intersection of Sand and Clay percentages
    - Using lists to obtain an value of T_{PSA}
- Based on expert soil science knowledge
  - Personal communication, Cathy Seybold, March 2016
  - Rawls and Brakensiek (1983)

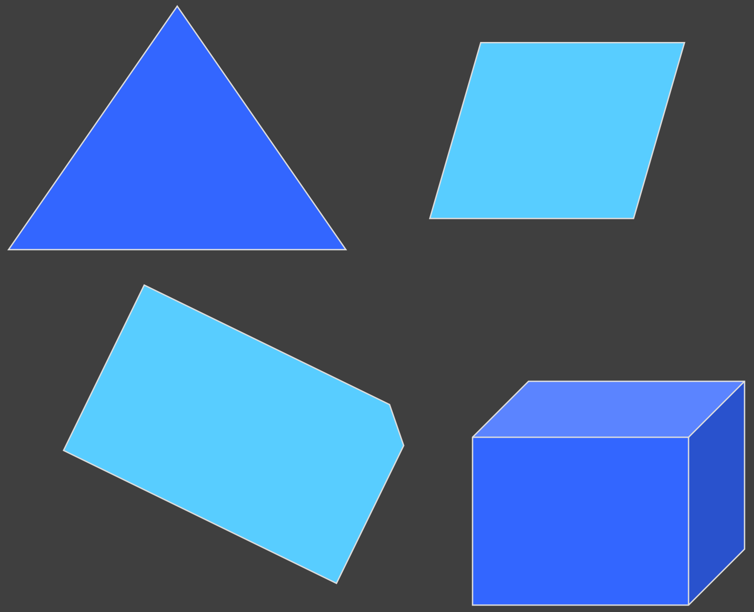


Reference: (Natural Resources Conservation Service, 2010)

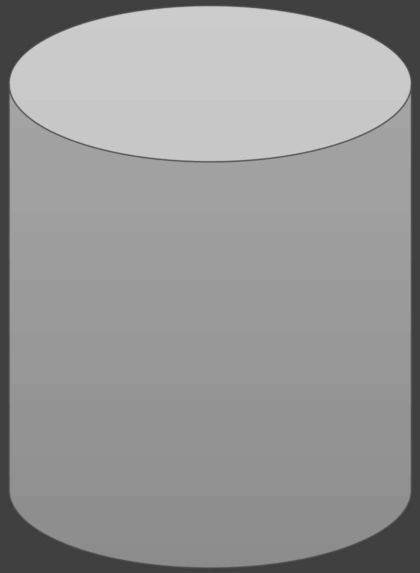
T_{PSA} K_{sat} Estimation Components



Clay



Sand



Bulk Density

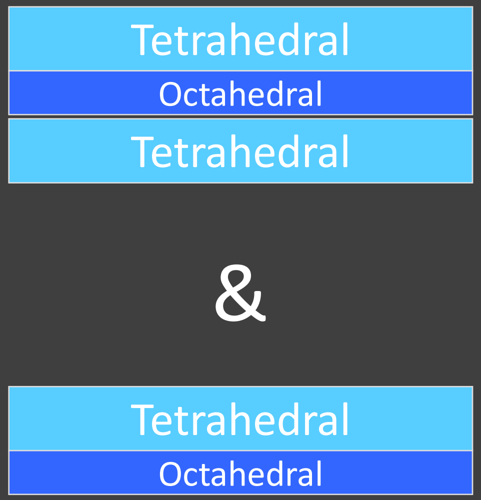
Saxton and Rawls, 2006 equations

Variable	Equation	Eq.
θ_{33}	$\theta_{33} = \theta_{33t} + [1.283(\theta_{33t})^2 - 0.374(\theta_{33t}) - 0.015]$ $\theta_{33t} = -0.251S + 0.195C + 0.011OM + 0.006(S \times OM) - 0.027(C \times OM) + 0.452(S \times C) + 0.299$	[1]
θ_{1500}	$\theta_{1500} = \theta_{1500t} + (0.14 \times \theta_{1500t} - 0.02)$ $\theta_{1500t} = -0.024S + 0.487C + 0.006OM + 0.005(S \times OM) - 0.013(C \times OM) + 0.068(S \times C) + 0.031$	[2]
K_S	$K_S = 1930(\theta_s - \theta_{33})^{(3-\lambda)}$	[3]

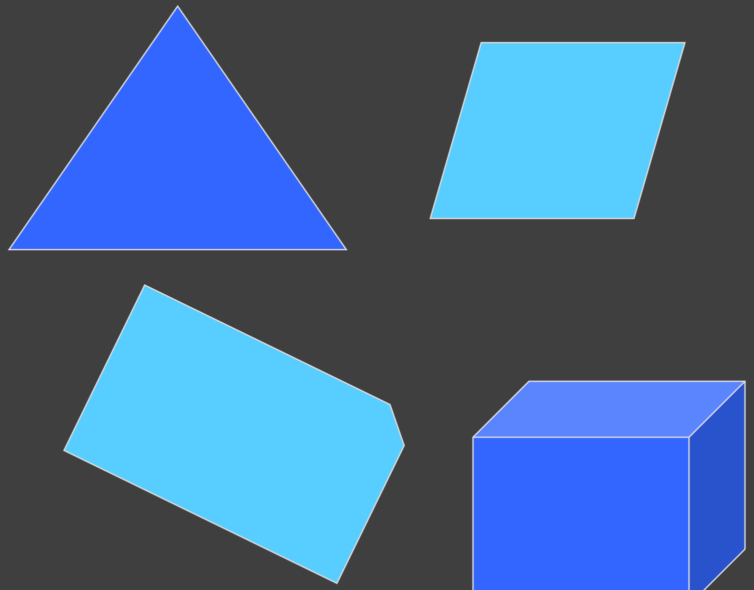
- Not only K_{sat}
  - Field Capacity (33 kPa)
  - Permanent Wilting Point (1500 kPa)
    - Converted to Plant Available water
      - 33 kPa – 1500 kPa

- Regression equations correlated using (2000) A horizons
  - B-C horizons not used
    - Because low OM %
- "Extreme" values removed
  - Bulk Density
    - < 1.0 and > 1.8 g/cm^{-3}
  - High OM
    - > 8 % (weight)
  - High Clay
    - > 60% (weight)
- Reduced A horizon correlation set
  - 1722 samples

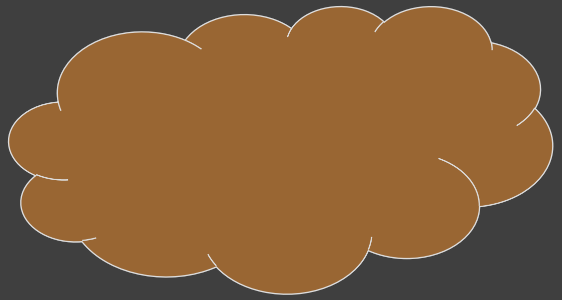
SR equation Components



Clay

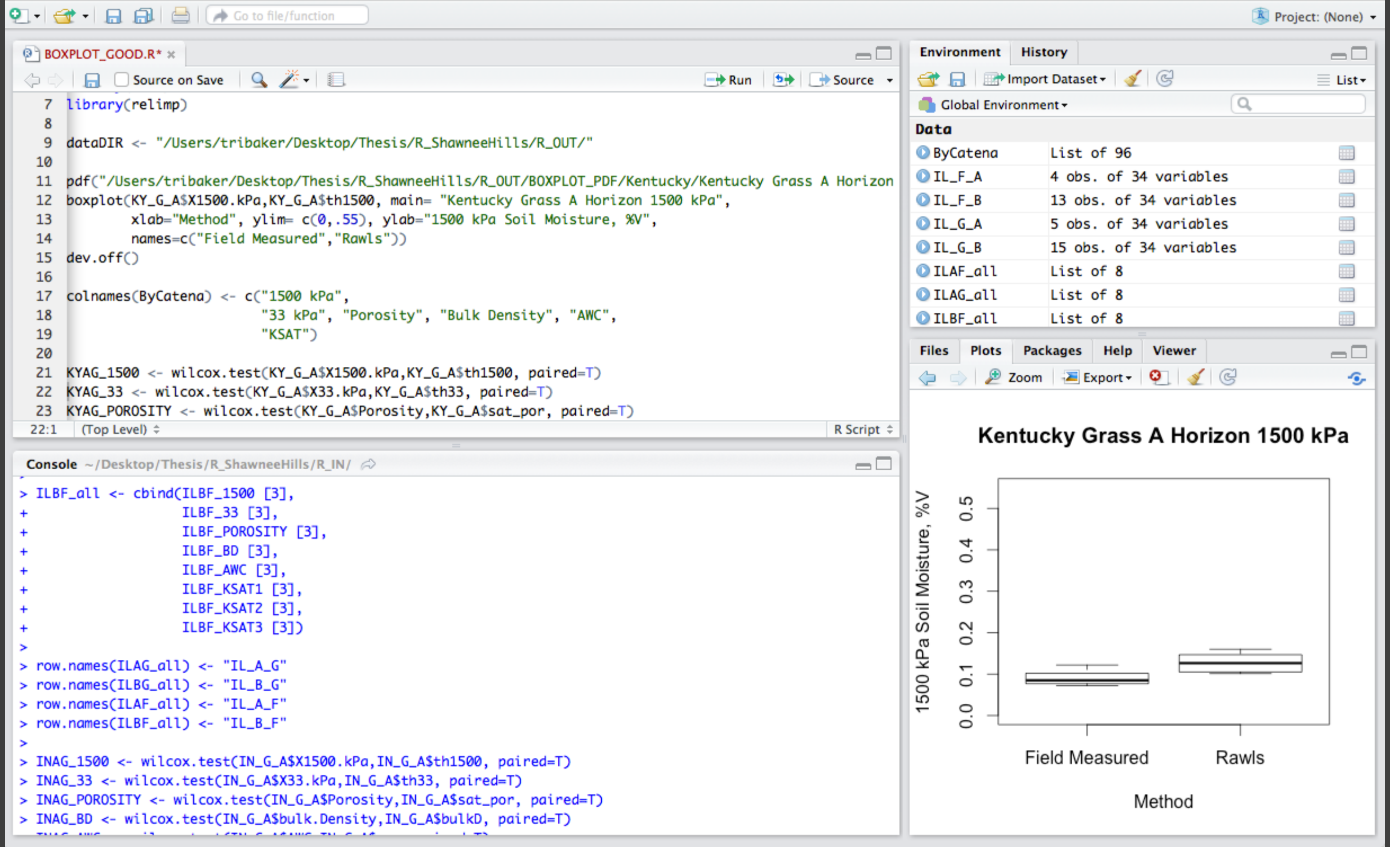


Sand



Organic Matter

Comparison: *in-situ* values v. estimated values



- Compared values in boxplots
- Assumed non-normal distribution
  - Wilcoxon rank-based test for significant difference

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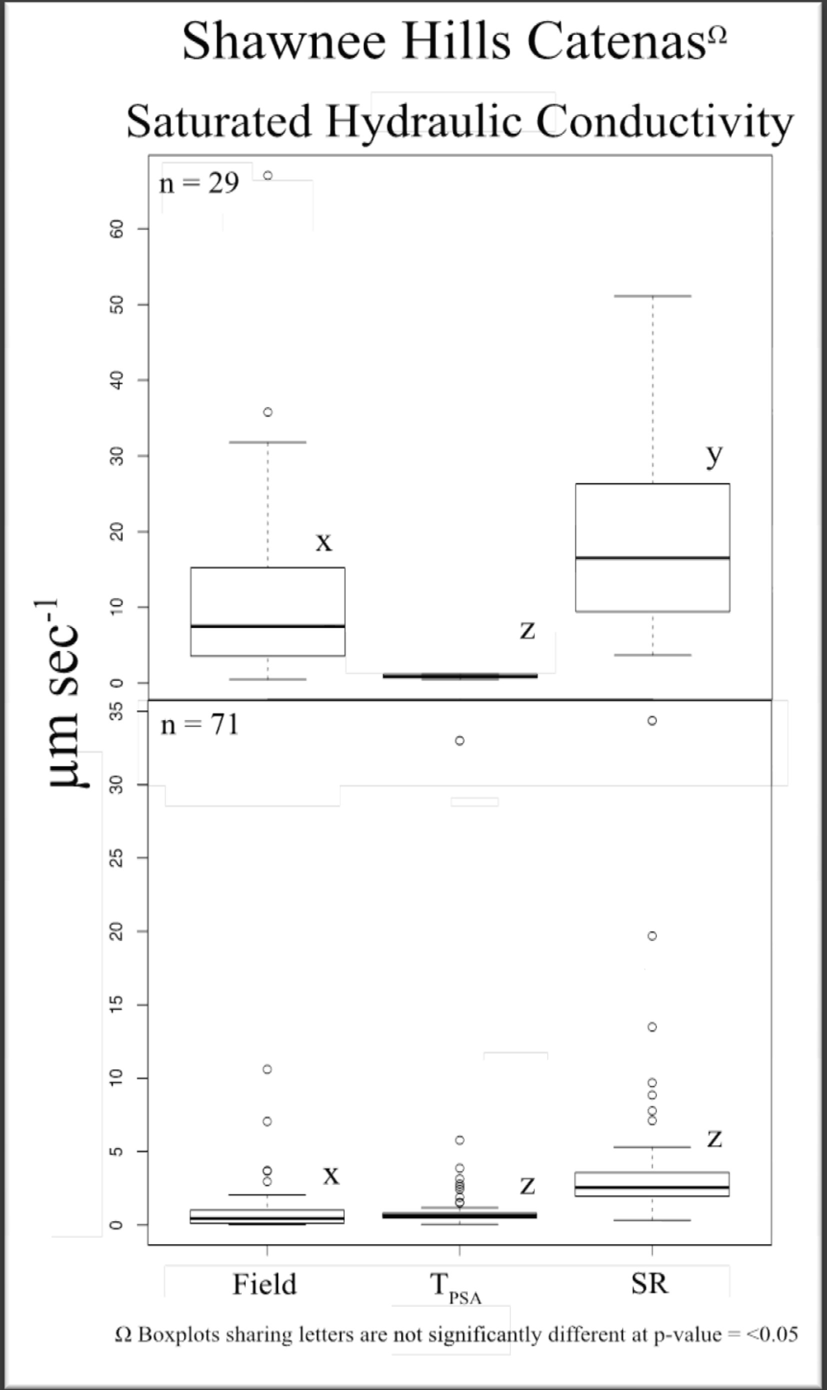
Saturated Hydraulic Conductivity

- Both methods found to be significantly different from *in-situ* measurements (*p-value* = <0.05)

- A Horizon
  - T_{PSA} under-estimated
    - 88 %
    - Average of 10.8 µm sec^{-1}
  - SR over-estimated
    - 61 %
    - 8.26 µm sec^{-1}

- B Horizon
  - T_{PSA} over-estimated
    - 44 %
    - 0.40 µm sec^{-1}
  - SR over-estimated
    - 291 %
    - 2.86 µm sec^{-1}



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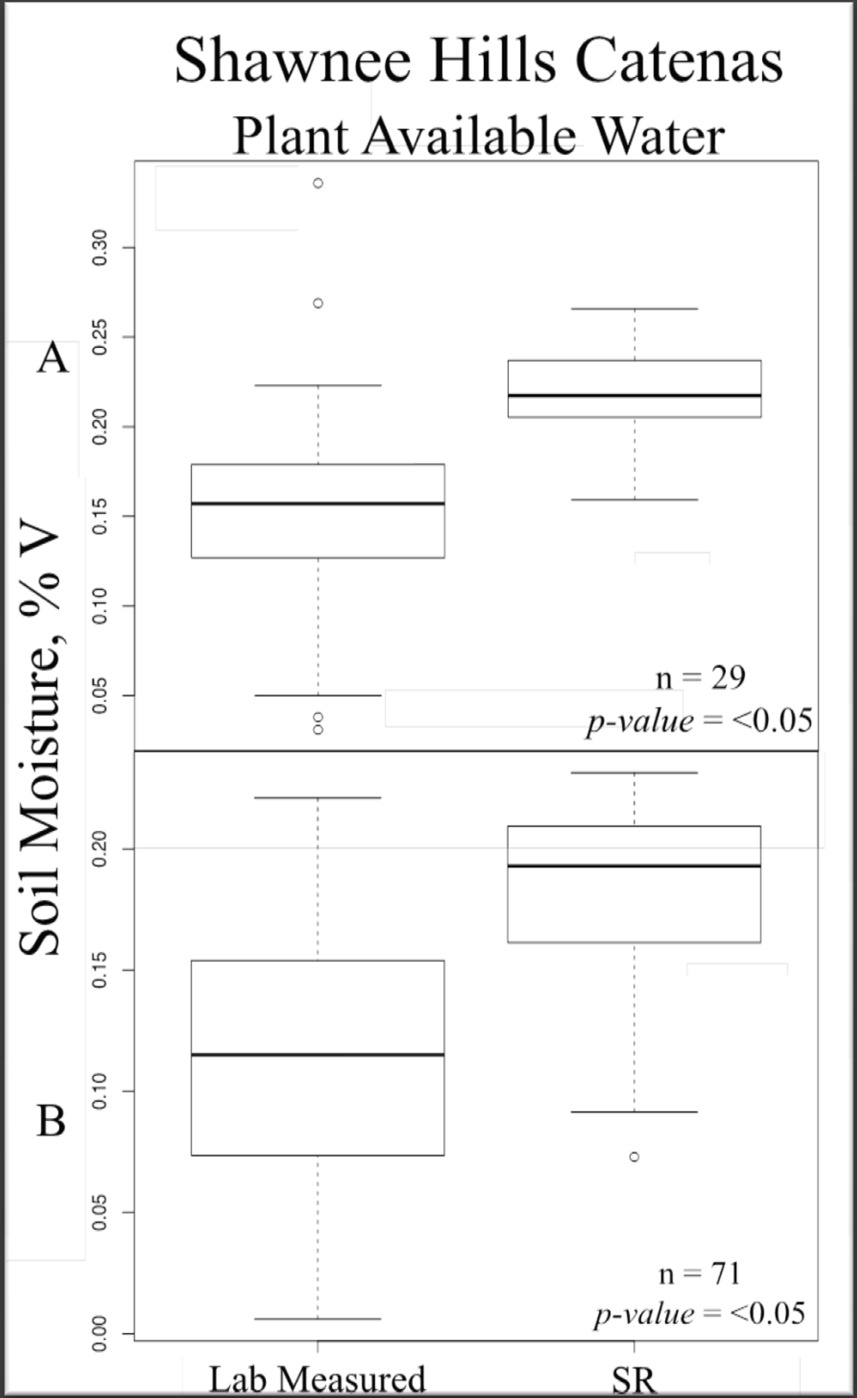
Plant Available Water

- SR found to be significantly different from lab measurements (*p-value* = <0.05)
    - A Horizon over-estimated
        - + 42 %
        - 6 % volumetric water content
    - B Horizon over-estimated
        - + 67 %
        - 8 % volumetric water content



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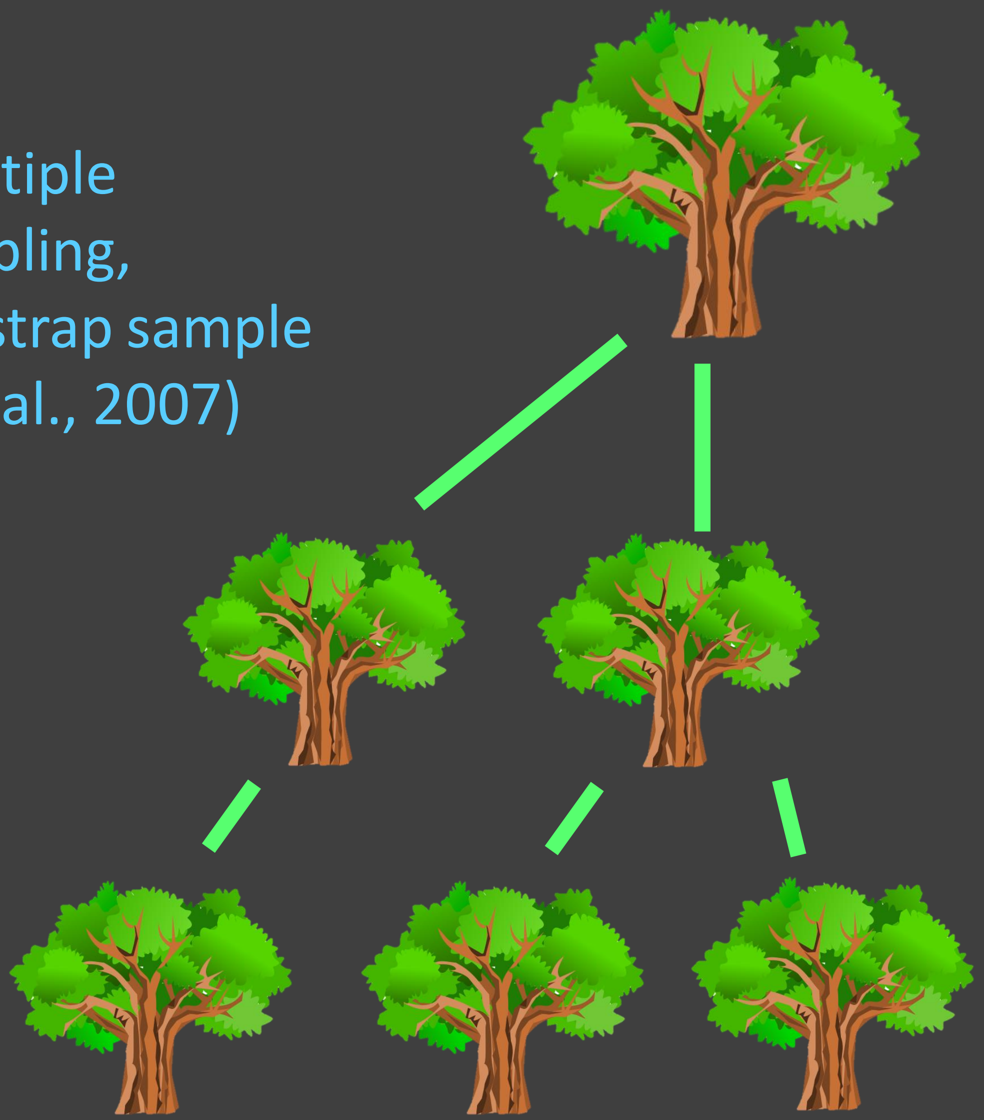
Comparison Results

- Saturated Hydraulic Conductivity
  - In both A and B Horizons
    - T_{PSA} and SR were significantly different from *in-situ* measurements *(p-value = < 0.05)*
- Plant Available Water
  - Estimated SR values for A and B Horizons were significantly different *(p-value = < 0.05*
- Another method needed
  - Random Forest (Regionally Informed)
    - Trained with the Six Shawnee Hills Catenas
    - Validated on two separate catenas

Random Forest Algorithm (Breiman, 2001)

- Identifies important covariates by generating multiple classification trees (a forest) using bootstrap sampling, randomly scrambling the covariates in each bootstrap sample and reclassifying the bootstrap sample (Peters et al., 2007)
- Handles both categorical and empirical values
    - Without creating dummy variables



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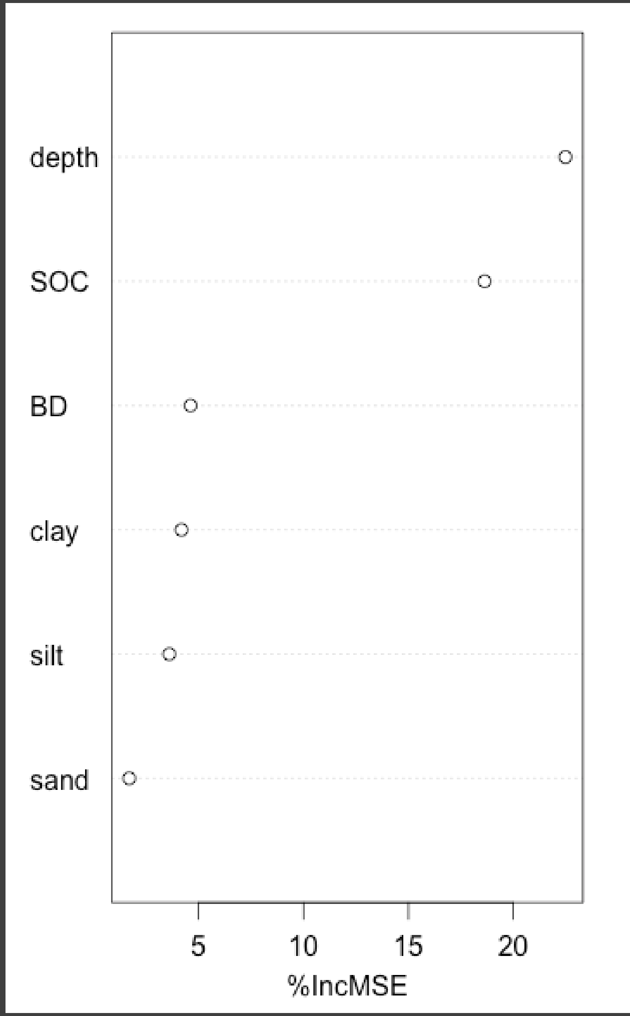
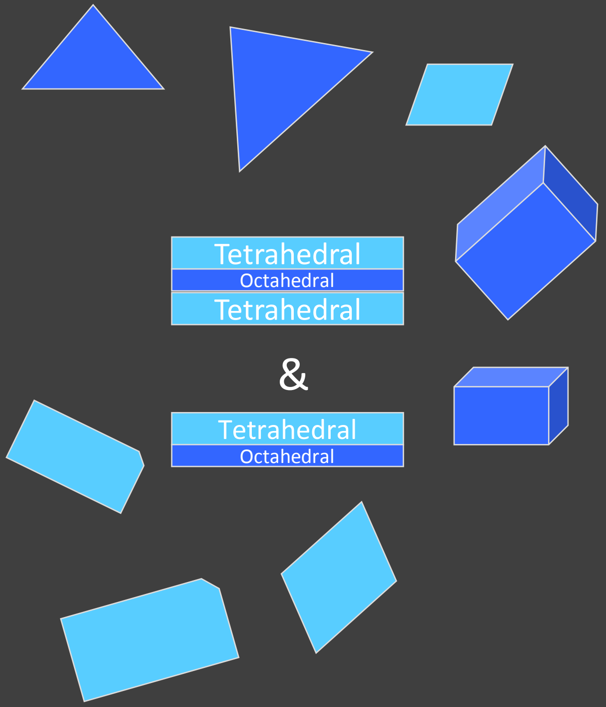
Building the Model (RF)

- Creating a classification model with all predictor covariates, ranking each predictor covariate, eliminating the covariate(s) with the lowest importance
  - Repeating until a desired threshold is reached
    - randomForest function in R
- Regional Approach
  - Can utilize the local factors and nuances
    - Traditional methods (linear) might not catch
- New (2001)
  - NRCS beginning to employ
    - RaCA (50+ cm bulk density)



RF Components



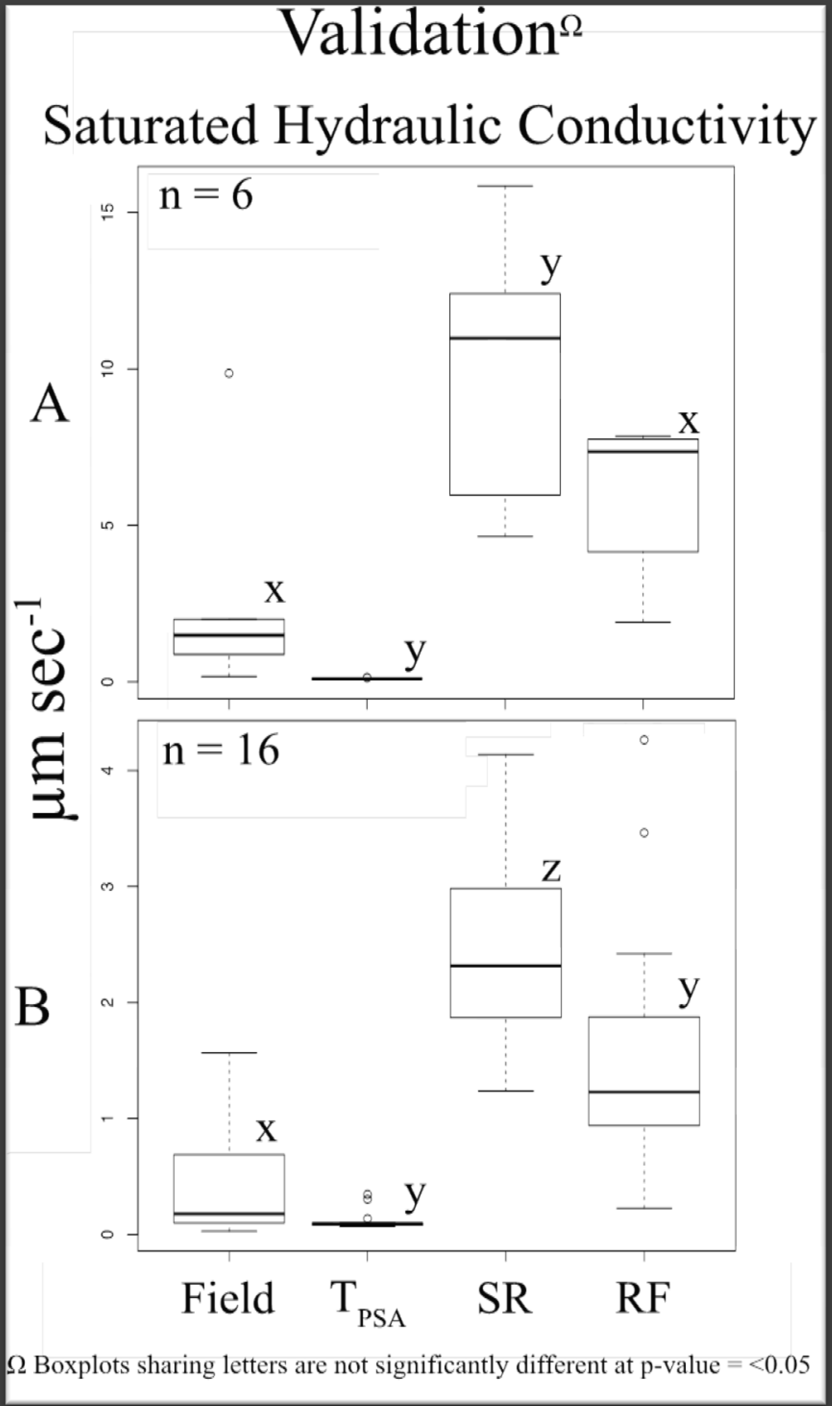
PSA

Depth of Sampling

Validation Catenas

Saturated Hydraulic Conductivity

- A Horizon
  - T_{PSA} under-estimated
    - 96 %
    - Average of 3.6 µm sec^{-1}
  - SR over-estimated
    - 283 %
    - 6.9 µm sec^{-1}
  - RF over-estimated
    - 129 %
    - 3.0 µm sec^{-1}
- B Horizon
  - T_{PSA} under-estimated
    - 72 %
    - 0.37 µm sec^{-1}
  - SR over-estimated
    - 467 %
    - 2.24 µm sec^{-1}
  - RF over-estimated
    - 248 %
    - 0.87 µm sec^{-1}



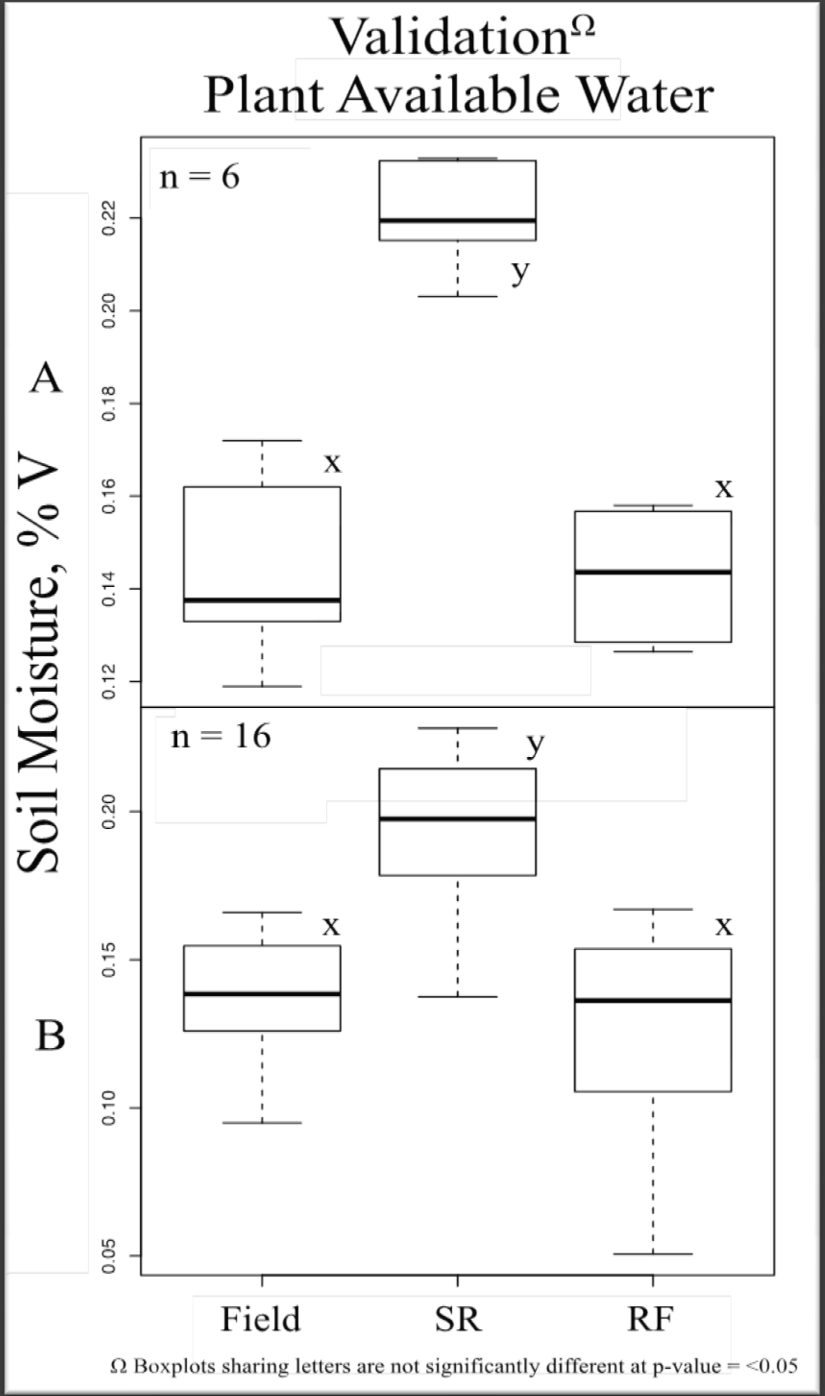
Validation Catenas

Plant Available Water

- SR significantly different from lab (*p-value* = <0.05)
- RF not significantly different from lab (*p-value* = >0.05)

- A Horizon
  - SR over-estimated
    - 54 %
    - 7.9 %, vmc
  - RF under-estimated
    - 0.5 %
    - 0.15 %, vmc

- B Horizon
  - SR over-estimated
    - 40 %
    - 7.2 %, vmc
  - RF under-estimated
    - 9.0 %
    - 1.3 %, v



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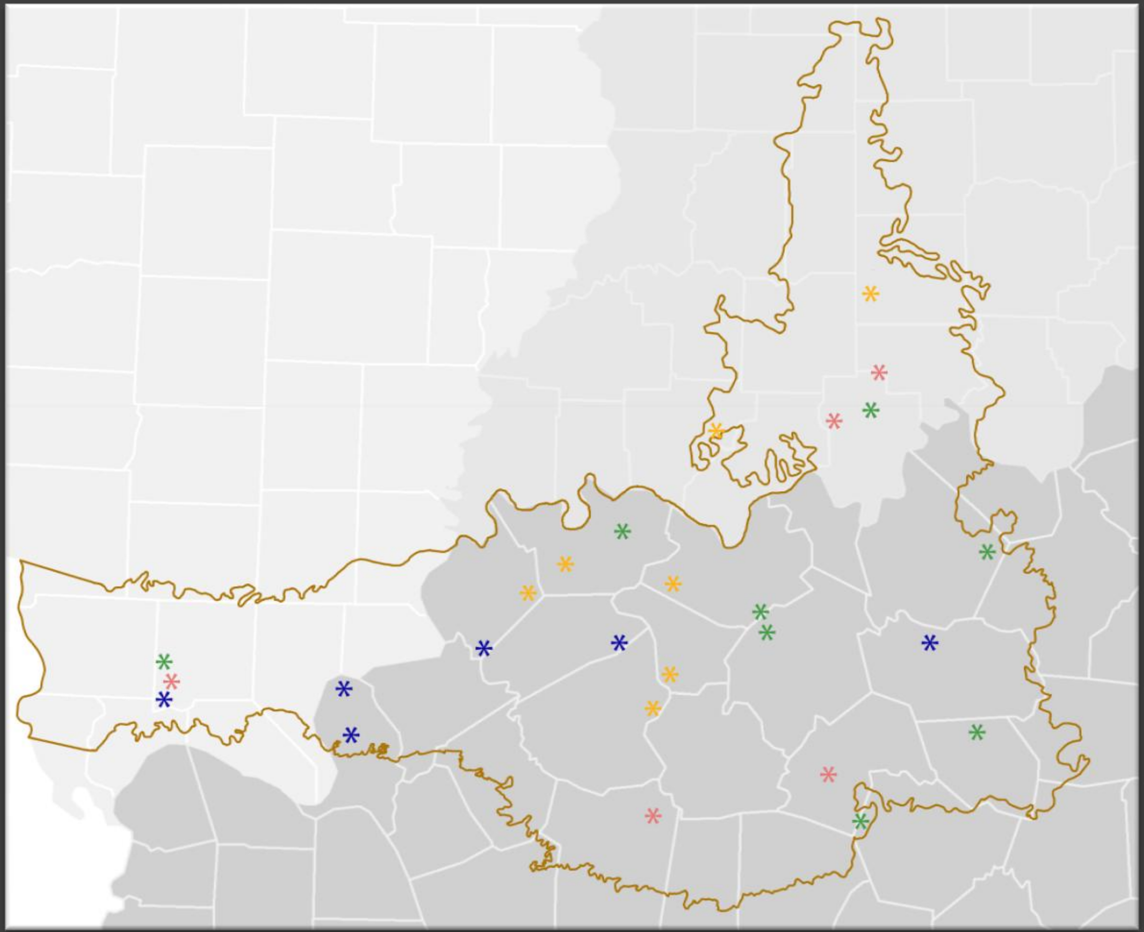
Conclusion

- PTFs are generalized correlations of an underlying database
  - Broad datasets
  - Issues can occur when downscaling to a specific region

- Building regional specific PTFs
  - Reveal regional specific correlations
  - Allowing upscaling correlations of several catenas to regional scale

Applying RF to RaCA



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Questions? Comments?

Thanks for your time

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